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THESIS

COMPARISON OF JANUS AND FIELD TEST AIRCRAFT DETECTION RANGES FOR THE LINE-OF-SIGHT FORWARD HEAVY SYSTEM

by

Eugene P. Paulo

September, 1991

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Comparison of Janus and Field Test Aircraft Detection
Ranges For The Line-of-Sight Forward Heavy System

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

The purpose of this thesis is to analyze the feasibility of accrediting the Janus combat simulation for use with an Army concept called Model-Test-Model. Aircraft detection ranges from an operational field test are compared to similar ranges generated by the Janus combat simulation. Means and distributions of detection ranges for both helicopter and fixed-wing aircraft are studied. Methods of collecting detection data in field tests and representing aircraft in Janus must be improved for Janus to be accredited for aircraft detection range analysis of field tests.

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I. INTRODUCTION

A. THESIS OBJECTIVE

The objective of this thesis is to validate or accredit the Janus combat simulation system for ground to air detections within the post-test phase of the Model-Test-Model (MTM) concept. The approach will be to compare field test detection range data of the Line of Sight-Forward-Heavy surface-to-air missile system with that of the Janus combat simulation.

B. DESCRIPTION OF THE LINE OF SIGHT-FORWARD-HEAVY (LOS-F-H) SYSTEM

For years, the Army has recognized the need for a capable low-altitude, short-range air defense weapon system to replace tne outdated Chapparal and Vulcan systems. The LOS-F-H should eventually fill that need.

The LOS-F-H is a surface-to-air system mounted on a modified Bradley fighting vehicle. The only major armament of the LOS-F-H is its missiles. The LOS-F-H carries eight missiles onboard. It is manned by a crew of three: a commander/radar operator (RO), a gunner/electro-optics (EO) operator, and a driver. The LOS-F-H has its own acquisition and tracking radar which can track on several aircraft while scanning for others out to a range of twenty kilometers. The

crew uses a Forward Looking Infrared (FLIR) sensor or an optical (TV) sensor to track and help identify the target. Identification of the target is finalized using the Identification, Friend, or Foe (IFF) device, which receives an encrypted transmission sent out by friendly aircraft [Ref. 1].

The LOS-F-H missile is designated as a 'laser beam rider' because it is guided by a coded laser beam from the fire unit. The laser beam rider capability lessens the effectiveness of the enemy's use of countermeasures to disrupt missile flight through radar jamming.

The LOS-F-H weapon system weighs approximately 31 tons fully loaded, including eight 112 pound missiles in ready-to-fire canisters. Figure 1 is a picture of the LOS-F-H and the crew positions.

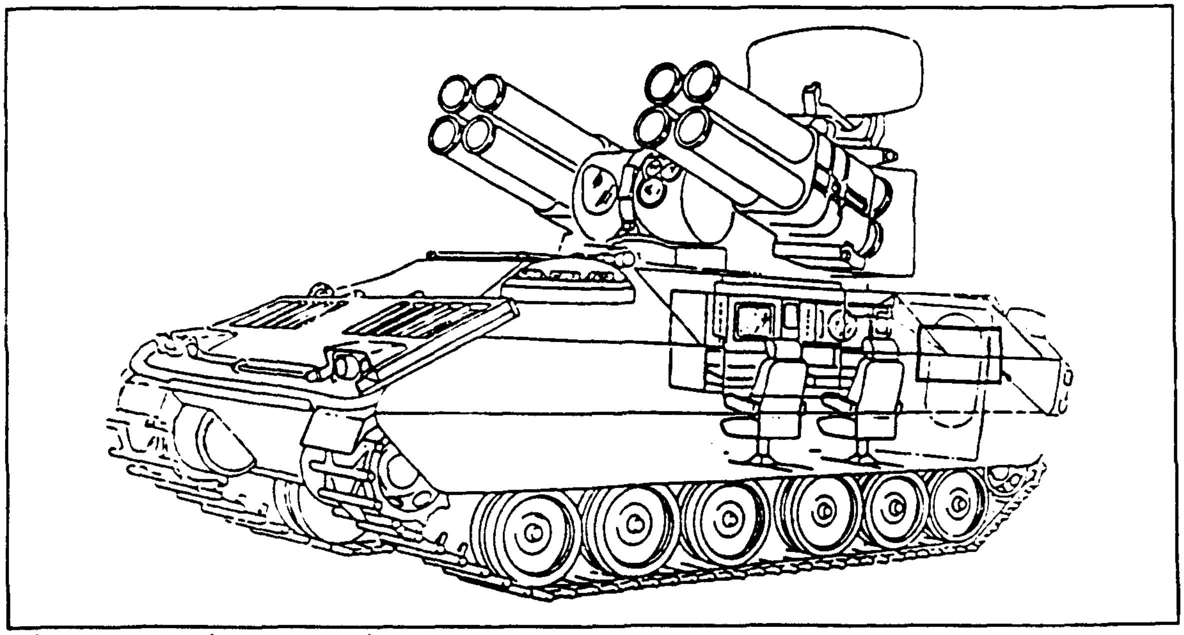

Figure 1 Line Of Sight-Forward-Heavy

C. DEFINITION OF DETECTION

For the Janus trials, aircraft detection occurs when the LOS-F-H radar determines that some type of airframe is approaching, records its location, and identifies the target as friendly or hostile. The field test trials require a further step for aircraft detection: a crewman must be aware of the approaching target. The differences in these two processes make their comparison difficult. Though hostile and friendly aircraft detections were recorded in both the field test and Janus, our concern will be with detections of hostile aircraft only.

D. MODEL-TEST-MODEL CONCEPT

Field tests are fundamental to the acquisition of any new weapon system. Critical to the quality of a field test is that it accurately portrays the capabilities of the system within its operational context. One method that will help improve the quality of field tests is Model-Test-Model.

The term Model-Test-Model refers to the three primary phases: the pre-test phase, the field test, and the post-test phase.

1. PRE-TEST PHASE

The pre-test phase involves use of a combat simulation model by members of the field test evaluation team, the Army proponent, the modellers, and maneuver unit leaders. During

this phase, scenarios are developed within the simulation that can be used during the field test. The scenarios must incorporate the restrictions placed on the test, including representation of the terrain, numbers of players, and the force mix. The maneuver unit leaders try to determine tactics for each scenario, such as routes of march and defensive positions. The results of the scenario development are used by the field test evaluation team in developing and improving their data collection and analysis methods and to improve the conduct of the field test. Tactics that were successful in both the model and field test should be provided to the Army proponent to update doctrine.

The pre-test phase also can provide training for the maneuver unit leaders. Many past tests have indicated that several trials in a field test may be necessary for player units to get adequately organized and trained. Exposure to the scenario, terrain, and systems that will be involved in the field test during the pre-test phase may make the earlier field trials better, since the maneuver leaders are presumably familiar with major facets of the field test from the outset.

2. FIELD TEST PHASE

During the field test phase, the system is tested under realistic combat conditions to determine its operational effectiveness and suitability. It is important that typical users of this system are used in the field test and that the

threat forces employed are realistic. The specified minimum acceptable operational requirements delineated by the system's proponent must be adequately tested.

The use of MTM in the pre-test phase allows the field testers to use improved scenarios derived from pre-test modelling. The amount of replication of the pre-test tactics employed may differ for force development tests and operational tests.

Force development tests are conducted early in the weapon acquisition process and are meant to examine the effectiveness of existing or proposed concepts of training, doctrine, organization, and material. Therefore, force development tests should include trials which attempt to replicate as closely as possible some of the tactics developed by the maneuver unit leaders during the pre-test modelling. This provides field test results for some of the tactics examined in the simulation and helps determine if these successes can be approximated in the testing environment.

Operational tests, both initial and follow-on, occur later in the acquisition process and are less controlled than force development tests. They focus on the operational effectiveness of new systems and whether they are worthy of production. Operational tests differ from force development tests in that tactical realism is critical and ground commanders do not follow a 'script'. Rather, maneuver leaders

use their own judgements in an operational test, with the aid of the knowledge gained from the pre-test phase.

3. POST-TEST PHASE

Following the field test, the post-test phase begins. The immediate goal of the post-test phase is to validate or accredit the simulation model. Since we are primarily concerned with post-test model accreditation, the process for accomplishing this goal is detailed in this thesis.

As a second goal of this phase, evaluators can use the improved simulation for cautious predictions. Constraints of the field test, such as numbers of players, dimensions of the maneuver areas, and types of terrain, could be altered within the simulation. Results of runs with the modified simulation model could add valuable information for consideration by the evaluator.

MTM combines force-on-force battle simulation and field testing with the goal of improving them both. MTM is used to support test design and evaluation of test results.

4. DEFINITION OF VALIDATION AND ACCREDITATION

Before a model can be used to represent an actual field test, it must be shown that the model is a measureably close representation of that field test. The degree to which it can be shown to represent the field test will determine whether the model is validated or accredited [Ref. 2].

The concepts of model validation and accreditation were

addressed by Walter Hollis, the Deputy Undersecretary of Defense for Operations Research. He defines model validation as follows.

> The process of determining that a model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model [Ref. 3].

In this thesis, our intent is not to attempt to show that the model is an accurate representation of the LOS-F-H field test, as we are concerned only with analyses of aircraft detection ranges.

On the other hand, accreditation is concerned with more specific applications. Mr. Hollis defines accreditation as follows.

> Certification that a model is acceptable for use for a specific type of application. Accreditation is possible even if the model is not fully validated [Ref. 3].

Determining that a model accurately represents all aspects of a field test may be difficult. Accreditation, or demonstrating that a model is accceptable for certain applications, such as a comparison of detection ranges, might be feasible.

E. HOW THIS THESIS FITS INTO MODEL-TEST-MODEL

In this thesis, we are concerned strictly with accreditation of the Janus model. Specifically, we compare aircraft detections by the Line of Sight-Forward-Heavy (LOS-F-H) from an actual field test conducted in May and June of 1990 with simulations of the selected test trials with the Janus

model. Only detections by LOS-F-H systems of fixed wing aircraft and helicopters are analyzed. In the next two chapters we discuss the LOS-F-H field test and the Janus simulation model.

II. CONDUCT AND DESCRIPTION OF THE FIELD TEST

A. DESCRIPTION OF THE FIELD TEST

1. FIELD TEST BACKGROUND

The purpose of the field test was to evaluate the operational effectiveness and suitability of the LOS-F-H platoon in performing its designated role of providing air defense for heavy maneuver forces in the forward area.

The agency conducting the field test was TRADOC Test and Experimentation Command, Experimentation Center (TEC). The test was an Initial Operational Test and Evaluation (IOTE). For the sake of simplicity, we will refer to it as the 'field test' throughout this document.

Over 1000 personnel participated in the field test, and almost 600 of them were members of tactical units from the Army, Air Force, and the Air National Guard. The field test took place at Fort Hunter Liggett, California in the spring of 1990.

2. DESCRIPTION OF INSTRUMENTATION

All ground vehicles and aircraft had sophisticated instrumentation packages installed. This equipment consisted of laser sensors and emitters which were intended to provide updates of battle progress. This capability is called real-time casualty assessment (RTCA). With this instrumentation on

each vehicle, player locations, as well as important events such as engagements, could be monitored and recorded. Much data gathering and analysis depended on the accuracy of this process.

3. FIELD TEST PHASES

The field test consisted of three phases: the pretest, exploratory trials, and record trials. The pretest began in late February 1990 and lasted until mid March 1990. During this time, personnel involved in the field test finalized individual training on their weapons. Additionally, all RTCA instrumentation packages were installed on the vehicles.

A total of 15 exploratory trials were conducted over an eight day period [Ref. 1]. The objectives of the exploratory trials included allowing maturation of the data collection and reduction procedures, resolving instrumentation problems, and providing an opportunity for test controllers and players to refine their procedures. Additionally, the exploratory trials provided objective evidence about whether instrumentation and players were ready to start record trials.

Fifty record trials were conducted from 9 April to 23 May 1990. The trials were conducted in the same manuever area, which had dimensions of approximately 15 kilometers by 15 kilometers. Each trial was a force-on-force battle which generally lasted about one hour. Normally, two trials were conducted each test day. The friendly units were designated

as Blue forces and the 'threat' units as Red forces. The battles involved Red and Blue mechanized forces of battalion strength. Table I shows the typical size and make-up of Blue and Red forces during a battle. For Red weapon systems, American made 'surrogates' were used. The surrogates are identified in the table in parentheses.

Table I BLUE AND RED FORCES IN LOS-F-H FIELD TEST

BLUE PLAYER	NUMBER OF SYSTEMS
M1A1 TANK	10
M3 CAVALRY FIGHTING VEHICLE	12
AH-1 COBRA HELICOPTER	2
OH-58 KIOWA HELICOPTER	3
A-10 THUNDERBOLT ATTACK PLANE	2
LINE-OF-SIGHT FORWARD HEAVY	4

RED PLAYER (SURROGATE)	NUMBER OF SYSTEMS
FUTURE SOVIET TANK (M60A3 TANK)	10
SOVIET BMP (M113 ARMORED PERSONNEL CARRIER)	12
HIND HELICOPTER (AH-64 APACHE)	3
HAVOC HELICOPTER (AH-64 APACHE)	1
HIP HELICOPTER (UH-60 BLACKHAWK)	4
FROGFOOT ATTACK PLANE (A-7 CORSAIR)	2

The LOS-F-H mission during all record trials was to defend the Blue maneuver force against air attack as the force conducted its mission. The Red forces had no comparable Air Defense Artillery asset.

4. FIELD TEST CONDITIONS AND THE SELECTION OF TRIALS

The conditions of the trials were varied. These conditions included north or south orientation, day or night, defense or offense, and the Mission Oriented Protective Posture (MOPP) of either 0 or 4. MOPP 4 indicates that all players must wear full protective chemical garments.

We did not attempt to make analyses related to all 50 field trials. Only four trials were analyzed, due to their identical conditions of daytime, defense, MOPP 0, and Blue in the South, and because these trials had the most helicopter and fixed-wing detection data available.

B. FIELD TEST RESOURCE LIMITATIONS

There were two resource limitations that could have impacted on the quality of the data resulting from the field test. One was the lack of artillery in any of the trials. The use of artillery might have caused the LOS-F-H systems to move more often, thereby reducing their effectiveness; artillery most likely would have destroyed several LOS-F-H systems. The result would have been fewer enemy aircraft detected.

A second limitation was a safety precaution that allowed fixed-wing pilots to fly no lower than 200 feet above the ground. The 'ground' was interpreted by the pilots to be the valley floor, and therefore meant they could fly closer to tree-top level when over hilly areas, since they would still be 200 feet above the valley floor. This precaution made detection of enemy fixed-wing aircraft more likely, since they were required to fly higher than what they probably would fly in combat. Higher flight altitude makes the aircraft more vulnerable to ground radar, as it has less chance of being masked by mountains or other terrain features.

III. DESCRIPTION AND USE OF JANUS SIMULATION

A. OVERVIEW OF JANUS

Janus is an interactive, force-on-force, high-resolution combat model used extensively throughout the Army. The original version of Janus was developed at the Conflict Simulation Center at Lawrence Livermore Laboratory for the purpose of creating a two-sided analytical and training tool to study the dynamic battlefield. It was later improved by the Janus Working Group at Tradoc Analysis Command (TRAC), White Sands Missile Range. Janus is intended for use at brigade-level and below. The Janus code is written in FORTRAN [Ref. 4].

The Janus simulation models combat systems, such as tanks and helicopters, the battlefield environment, and each system's interaction with other systems and their environments. The characteristics of these combat systems include descriptions of the weapons carried, weapon capabilities, and much more.

B. DEVELOPMENT OF THE JANUS TRIALS

1. LOADING THE START POSITIONS AND ROUTES

Prior to simulating a field test trial in Janus, it was necessary to enter the start locations and movement routes of all players. These start locations and movement routes were

the only data translated directly from the field test to the Janus trials. This was done using a combination of FORTRAN programs, written at TRAC-Monterey and TRAC-White Sands by Mr. Al Kelner and CPT Allen East that rapidly loaded the start locations and routes for each trial.

2. DESCRIPTION OF JANUS UTILITIES

Before addressing the specific development of the trials, we describe how Janus can be manipulated by the user. This is accomplished using four user-friendly utilities built into the simulation software. The four utilities are the symbol editor, the PH/PK (probability hit/probability kill) editor, the graphic terrain editor, and the scenario editor [Ref. 4].

The symbol editor allows the creation or definition of the graphic symbols used by Janus to mark unit locations. Symbols may be drawn as simple standard military graphics or as very detailed silhouettes. The symbol editor contains many pre-defined symbols that the user may select.

The PH/PK editor allows editing of data used to determine lethality over range for shooter-target pairs. Not only is range varied in these data sets, but also the postures of the shooter and target. For example, PH/PK varies for a moving or stationary shooter, as well as with a moving or stationary target. A specific Janus file can contain up to 1000 PH/PK data sets; each set represents the hit and kill probabilities of a particular shooter against a particular target.

The graphic terrain editor allows input and modification of terrain features, such as roads and vegetation, on a three dimensional terrain grid. The terrain resolution used in the analysis was 50 meters. This 50 meter resolution means that at every 50 meter interval in both an east/west and north/south direction, a terrain height reading was made and elevations between adjacent data points were interpolated to provide a relief representation [Ref. 5]. Janus can be used with higher or lower terrain resolution as well. All Janus map displays use digitized data from the Defense Mapping Agency and land satellite data.

The scenario editor provides access to system/weapon characteristics, battlefield descriptive parameters, and scenario force structures. Up to 198 different systems can be defined and their characteristics can be varied in numerous ways.

3. DEVELOPMENT OF JANUS SCENARIOS AND TRIALS

Only the terrain editor and scenario editor were used extensively in Janus scenario development. The Fort Hunter Liggett terrain representation we used for our Janus trials was drawn from the Janus database. The graphic terrain editor allowed two improvements in the terrain representation that were based on personal knowledge of the area. One improvement was the addition of roads, which allowed vehicles to travel along roads in the simulation as they did in the

field test. The other change was the addition of vegetation that was missed in the database, yet was critical to proper representation of the maneuver area.

The scenario editor was used extensively to create realistic Janus scenarios. The most critical concerns were accurately constructing the parameters of the LOS-F-H system and recreating the flight behavior of the fixed-wing aircraft and helicopters. Important LOS-F-H parameters included radar and sensor type, maximum detection range, detection probability of the LOS-F-H at certain ranges against various aircraft, and maximum engagement range. Critical aircraft parameters were flight speed and flight altitude. The values of these parameters were derived from the field test reports, conversations with the field test coordinator and two Janus programmers, and, where necessary, personal judgement [Ref.6].

C. UNCERTAINTY OF PARAMETERS

While most of the data described above were available, certain information was not. Most significant among missing data were the probabilities of detections for the LOS-F-H against different types of aircraft. These values were estimated using guidance from a White Sands Missile Range Janus programmer and personal judgement [Ref. 6].

IV. ANALYSIS OF FIELD TEST AND JANUS DETECTION DATA

A. REASONS FOR DIFFICULTY IN COMPARING DETECTION DATA

Research has revealed that comparing detection data from the field test to detection data generated in Janus will be difficult. One reason is the difficulty in measuring detections in a field test. The Real Time Casualty Assessment (RTCA) system cannot measure aircraft detections by individual soldiers manning equipment. Additionally, shortcomings in Janus and the field test restrict the ability to duplicate the field test environment. These problems are discussed in detail below.

1. FIELD TEST DETECTION DATA GATHERING PROCESS

As described in Chapter II, the Real Time Casualty Assessment (RTCA) system was effectively used to gather much data during the field test. However, the RTCA system could not provide detection data. According to Major Larry Dubois, the test coordinator from TEC, LOS-F-H detection data was acquired solely through analysis of video camera records.

Each LOS-F-H system had a video camera recording the crew's actions and words throughout the trial. The video camera was placed behind the crew and revealed their actions and verbal communications. Personnel doing the reconstruction selected 'target handoff' as an overt action to indicate that

a target was about to be engaged. 'Target handoff' occurred when the radar operator (RO) designates one of the targets under track to the gunner/electro-optics (EO) operator for engagement. This could be verified by a red button, visible on video, that illuminated when 'target handoff' occurred. By observing the time into the trial set in the recording, the range of the aircraft at 'target handoff' was determined by the video reviewer by obtaining the location of the LOS-F-H and the aircraft from the movement file. Detections were then determined by backtracking from 'target handoff' to another overt action, generally a verbal cue, alerting the video reviewer that a detection was made at that time. The range of detection was then calculated similarly to 'target handoff' range.

This process has several problems. First, only those detections that led to engagement, as indicated by 'target handoff', were noticed. A significant amount of data may have been lost, since many detections likely occurred which were never recorded because the particular LOS-F-H involved may not have been able to engage each target it detected. Additionally, the recorded detection ranges will have random errors, since the ranges are not actual, but rather were estimated by the video reviewers who depended on an overt sign rather than an actual detection. Finally, recorded detection ranges will tend to be shorter than detection ranges actually were. As mentioned earlier, detection occurs when a LOS-F-H

system recognizes a target and identifies it as hostile. The time of this event cannot be determined through analysis of the test data. This overt sign of detection occurred at an unknown time after the LOS-F-H detected the target, and the approaching target moved an unknown distance during this time. This problem must be taken into consideration before any conclusions can be drawn from detection range analyses.

Another limitation of the test range instrumentation is its inability to determine aircraft elevation. Knowing the altitudes of fixed-wing aircraft and helicopters during the field test is important for accurately representing the field test in a simulation.

2. AIRCRAFT FLIGHT REPRESENTATION IN JANUS

The most significant problem in attempting to replicate the field test in Janus had to do with representing aircraft flight characteristics. An actual attacking aircraft has the ability to quickly change altitude and speed in order to confuse enemy air defenses or to deliver its ordnance and quickly leave the area. A critical limitation of Janus is that each aircraft can have only two flight speeds and two flight altitudes which most likely cannot closely replicate the actual attack profile of an aircraft.

Additionally, there are two basic flight modes that an actual aircraft may use. One is 'constant altitude', in which an aircraft remains generally at a set altitude above a fixed

level on the ground (often sea level), regardless of changing terrain elevation. Fixed-wing aircraft in the field test used a version of this method, flying generally at a constant 200 feet above the level of the valley floor. The other flight mode an aircraft may use is called 'nap of earth' or terrain following. The altitude of an aircraft using this mode follows the changing elevation of the terrain. During the field test, helicopters used this tactic.

Only the 'nap of earth' mode of flight is available in Janus, and therefore maintaining level flight paths for fixed-wing aircraft had to be approximated. This was done by using both available altitude settings, one set at 200 feet (64 meters) for any portion of a flight path segment over a valley floor and the other set at 50 feet (16 meters) for a flight path segment over mountains. The height of 50 feet was chosen since the average elevation of the mountainous terrain above the valley floor is 150 feet.

This limitation of Janus would seem to have great impact on fixed-wing detection data. Fixed-wing aircraft in Janus cannot fly steadily at 200 feet altitude as the fixed-wing aircraft generally did in the field test. Additionally, the approximation described above relies on an inexact estimation of the average elevation over mountainous terrain. Yet the results of a sensitivity analysis indicates that the effects of this estimation may be insignificant.

A data sample of detection ranges containing three iterations of one trial with the average elevation over mountainous terrain set at 80 feet (26 meters) were compared to a data sample of detection ranges of three iterations of the same trial using the original elevation over mountainous terrain of 50 feet (16 meters). The method of comparison was a two-sided Mann-Whitney test. These two data samples were combined and the detection ranges were ranked. The average ranks of the two data samples were close at 57.16 and 63.23. Due to a sufficiently large sample size of over 100, the Mann-Whitney Z statistic is applicable. The null hypothesis is that the distributions of the two data sets are equal. The Z statistic for this test is .949, and at a significance level of .05, the null hypothesis cannot be rejected. The STATGRAPHICS 5.0 software package was used in this and all other analyses in this thesis [Ref. 7]

Therefore, while the availability of only a 'nap of earth' flying mode in Janus makes a comparison of fixed-wing detection data flawed, it appears that the approximation used does not add significant additional error.

B. ANALYSIS OF FIXED-WING DATA

The fixed-wing data used in our analysis came from four similar trials. Each trial was conducted during daylight hours, had the Blue forces in the defense, and was conducted in a chemical and nuclear free environment.

The field test data contained at most one detection per pass through the manuever area for every fixed-wing aircraft. The planes always flew in pairs and made four or five passes during each trial. Each trial, therefore, had eight to ten detections recorded.

Each set of Janus data had some repeated detections. To account for possible dependence between ranges of repeated detections, these repeated data points were eliminated, so only the initial detection ranges remained. No Janus iteration had more than six repeated detections.

A summary of the sample sizes of fixed-wing data is displayed in Table II below. The number in each box reflects the sample size in each category. The sample sizes of Janus trials are a result of five independent iterations per trial, while the field test data comes from only one iteration.

Table II FIXED-WING DETECTION SUMMARY

	TRIAL A	TRIAL B	TRIAL C	TRIAL D	TOTAL
JANUS*	45	78	79	54	256
FIELD TEST	10	9	12	10	41
TOTAL	55	87	91	64	297

* 5 Janus Runs Pooled

A comparison of the fixed-wing detection data is displayed in Figure 2. This series of box-plots allows comparisons of the Janus and field test data from each trial side-by-side. The boxes show the median of each data set as well as its inter-quartile range. This plot shows no strong evidence of a difference in means between Janus and field test fixed-wing data of a common trial.

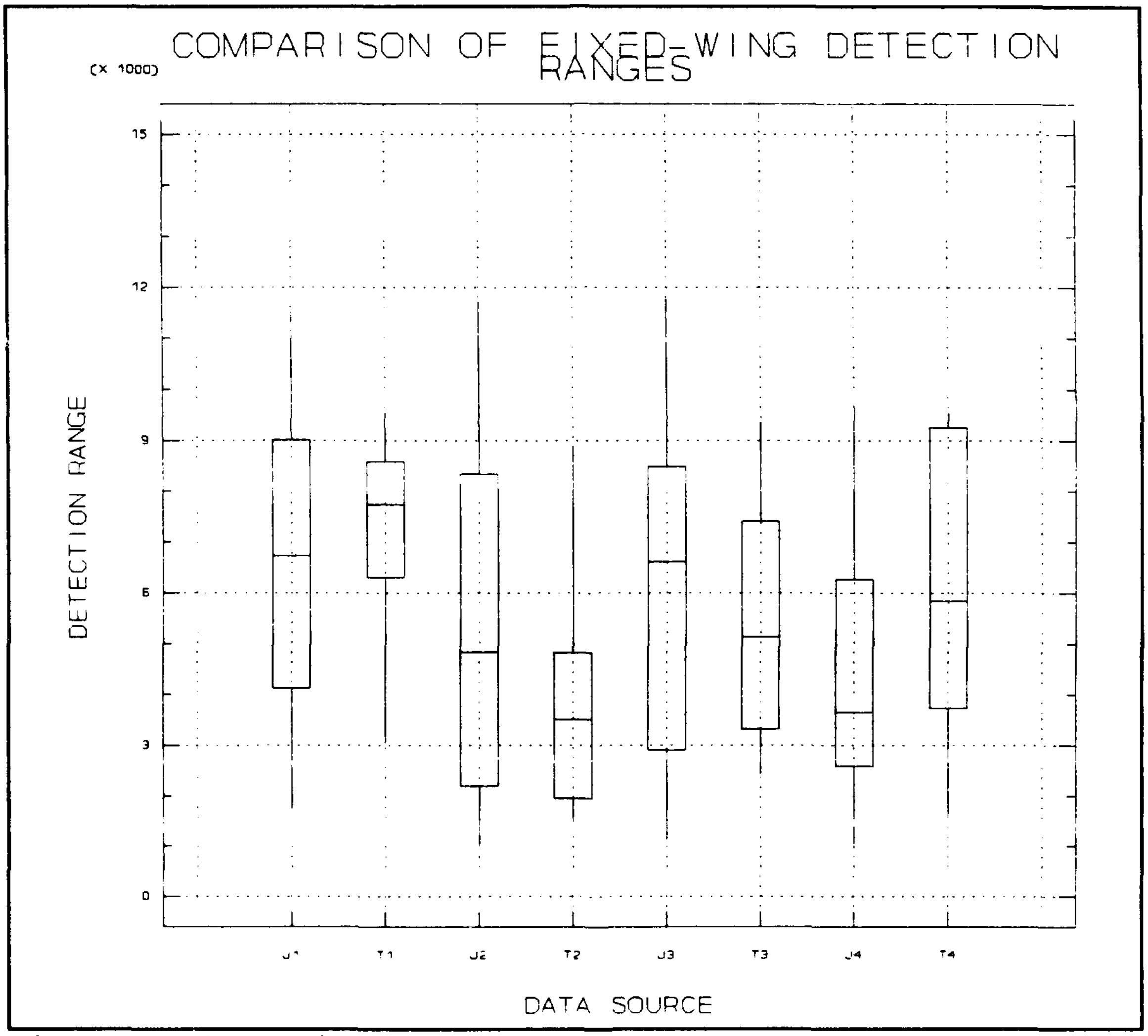

Figure 2 Fixed-Wing Box Plots

A Two-Factor Analysis of Variance (ANOVA) was used to test for equivalance of means of detection ranges between trials and between Janus and field test data for fixed-wing aircraft. The ANOVA summary table is shown in Table III. The two factors, or sources of variation, are labeled as trials and data source, and are related to testing the difference between trials and the difference between multiple Janus iterations and the field test data.

Table III ANOVA TABLE FOR FIXED-WING AIRCRAFT

SOURCE OF VARIANCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	SIG LEVEL
TRIALS	97,571,767	3	32,523,922	3.627	.0135
DATA SOURCE	275	1	275	.000	.9956
INTERACTIONS	40,502,645	3	13,500,882	1.506	.2132
RESIDUAL	2,596,280,000	289	8,967,573		
TOTAL	2,829,300,000	296			

STATGRAPHICS 5.0 has two methods of computing sums of squares for the ANOVA table. The method we used, designated as Type III, computes the additional sum of squares for each factor as if it were added to the model last. This is the method recommended for use with an unbalanced design [Ref. 7].

Between the four different trials, the F-ratio was 3.627 (df=3, 289) with a significance level of .0135, indicating a

significant difference between means. Between Janus and field test data, a very small F-ratio resulted in a significance level of .9956, revealing a strong indication of no significantly different means. The interaction of the two effects is insignificant as seen by its F-ratio of 1.506 (df=3, 289) and significance level of .2132. However, the plot seen in Figure 3 below suggests some possible interaction. This conflict between the F-test and interactions plot could be a result of the small sample sizes of the field test data. But the apparent crossover may be due to random error; the standard error of the means for field test data for each trial is approximately 1000 meters, while that for Janus data for each trial is approximately 375 meters. The standard error was calculated by dividing the standard deviation of every field test or Janus detection data set by the number of detections in that particular data set. Overall, we conclude there is not a significant interaction between trials and source (test or Janus).

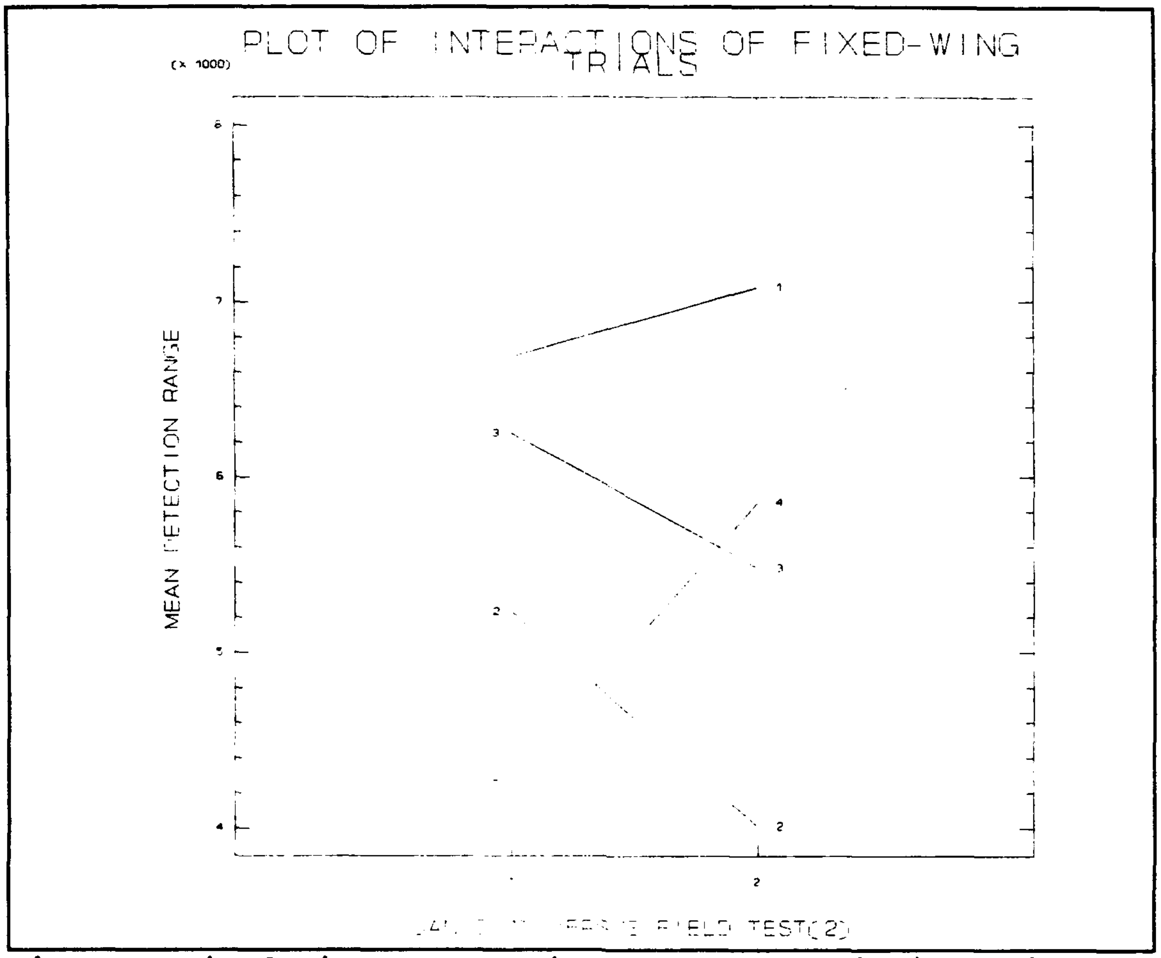

Figure 3 Fixed-Wing Interactions. Numbers Signify Trial.

To check the adequacy of the ANOVA model for fixed-wing aircraft data, the data were tested for normality in distribution of residuals and for equality of variance. The histogram plot of residuals versus a normal curve is shown in Figure 4. It indicates an apparent lack of normality of the residuals. A Chi-Square Goodness of Fit Test of the fixed-wing data gives a chi-square statistic of 58.47 (df=16). The corresponding significance level was .000, verifying that the

residuals do not appear to be normally distributed. This is not a great concern, due to the robustness of the ANOVA with regard to normality [Ref. 8]. Nevertheless, the distribution of the residuals of the log of the fixed-wing data were examined and did not appear normal. Ratios of sample variances between corresponding Janus and field test trials and from trial to trial resulted in values close to one. Additionally, 95% confidence intervals for ratios of variance include the value of one for each of the trials. Therefore a hypothesis of equality of variance cannot be rejected.

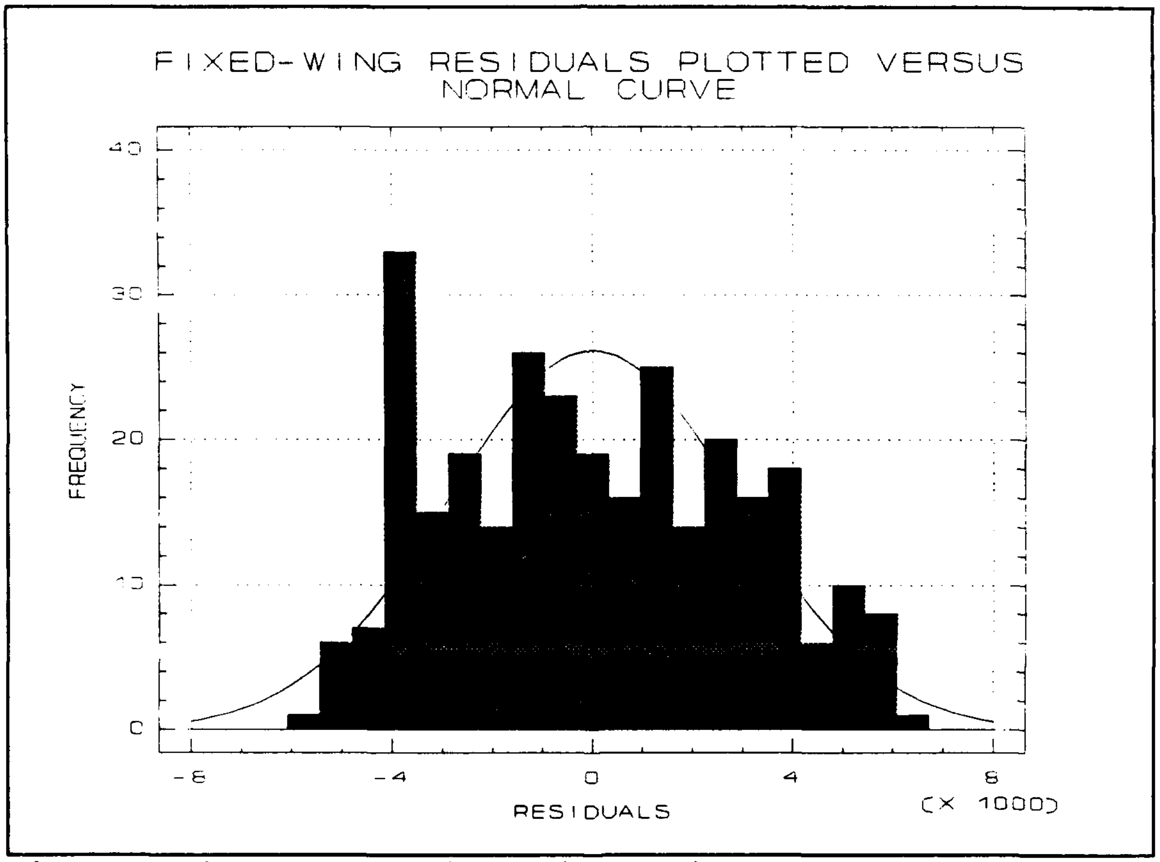

Figure 4 Histogram Of Fixed-Wing Residuals Versus Normal Plot

An additional Two-Factor ANOVA was conducted using the four trials versus the individual Janus runs and the field test. The purpose of this test was to examine the effect of the individual Janus runs and any resulting residuals. This was accomplished by separating the data source factor into its 5 Janus and a field test level. Table IV displays the results of this ANOVA.

Table IV ANOVA OF FIXED-WING DATA BY INDIVIDUAL JANUS ITERATION

SOURCE OF VARIANCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	SIG LEVEL
TRIALS	169,800,000	3	56,600,498	6.203	.0004
DATA SOURCE*	36,629,000	5	7,325,743	.803	.5485
INTERACTIONS	96,229,338	15	6,415,289	.703	.781
RESIDUALS	2,491,200,000	273	9,125,252		
TOTAL	2,829,300,000	296			

* 5 Individual Janus Iterations and the Field Test Looked at Separately

The significance levels above verify the previous ANOVA, in that the difference in means between trials is quite significant, while the differences in means between Janus iterations and the field test may not be significant. Additionally, the ANOVA shows no interactions between the two sources of variance.

C. ANALYSIS OF HELICOPTER DETECTION DATA

The helicopter detection data we considered are for the same four trials as above for the fixed-wing case. Each field test trial contained approximately 30 helicopter detections, while five iterations of each Janus trial resulted in about 100 detections when pooled. Both sets of helicopter data contained repeated detections of a given helicopter, as in the Janus fixed-wing data, and to avoid dependency among detection ranges, all were removed but the first of multiple repeated detections. Table V below shows a summary of the counts of helicopter detection ranges.

Table V SUMMARY OF HELICOPTER DETECTION RANGES

	TRIAL A	TRIAL B	TRIAL C	TRIAL D	TOTAL
JANUS*	95	147	99	98	439
FIELD TEST	29	40	19	22	110
TOTAL	124	187	118	120	549

* 5 JANUS RUNS POOLED

A graphical comparison of the helicopter data is indicated by the multiple box plots in Figure 5. The differences between Janus and field test ranges is obvious, as the Janus ranges are larger than the field test ranges in all cases.

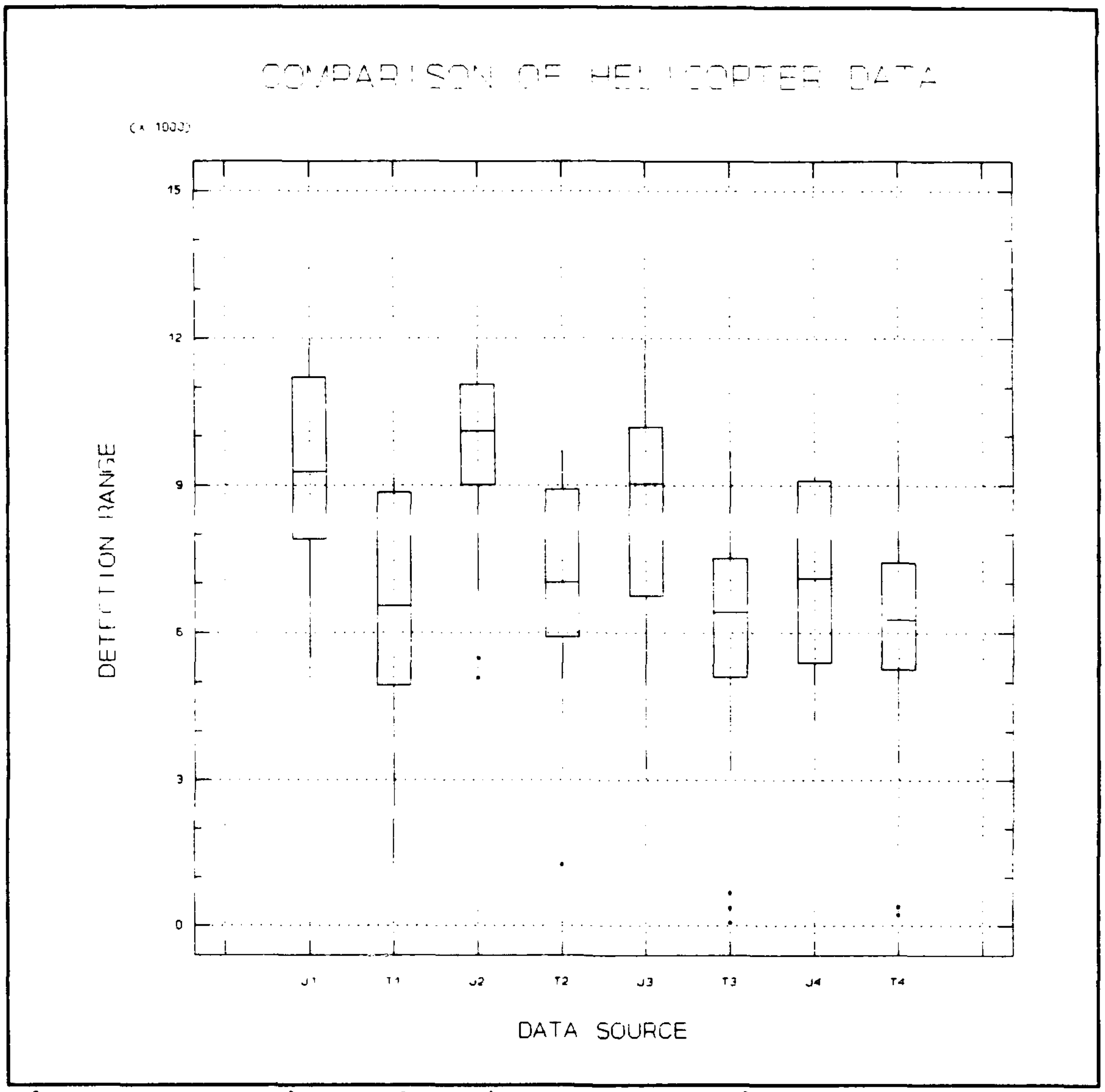

Figure 5 Comparison of Helicopter Detection Ranges

The helicopter detection data were compared with a Two Factor ANOVA. The ANOVA summary table is shown in Table VI. The two factors are the data source (Janus or field test) and the trials. This ANOVA gave large F-ratio values for trials and data source, indicating that there are significant differences in the means related to both factors. The F-ratio

for interactions between trials and data sources is 3.493 (df=3, 541) with a significance level of .0155, indicating there is significant interaction between trials and data sources. However, a plot of these interactions, seen in Figure 6, shows the interaction is due to only trial 4.

Table VI ANOVA TABLE FOR HELICOPTER DATA

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	SIG LEVEL
TRIAL	132,660,000	3	44,222,000	10.230	.000
DATA SCURCE	442,580,000	1	442,580,000	102.387	.000
INTERACTIONS	45,289,872	3	15,096,624	3.493	.0155
RESIDUAL	2,338,500,000	541	4,322,579		
TOTAL	3,242,600,000	548			

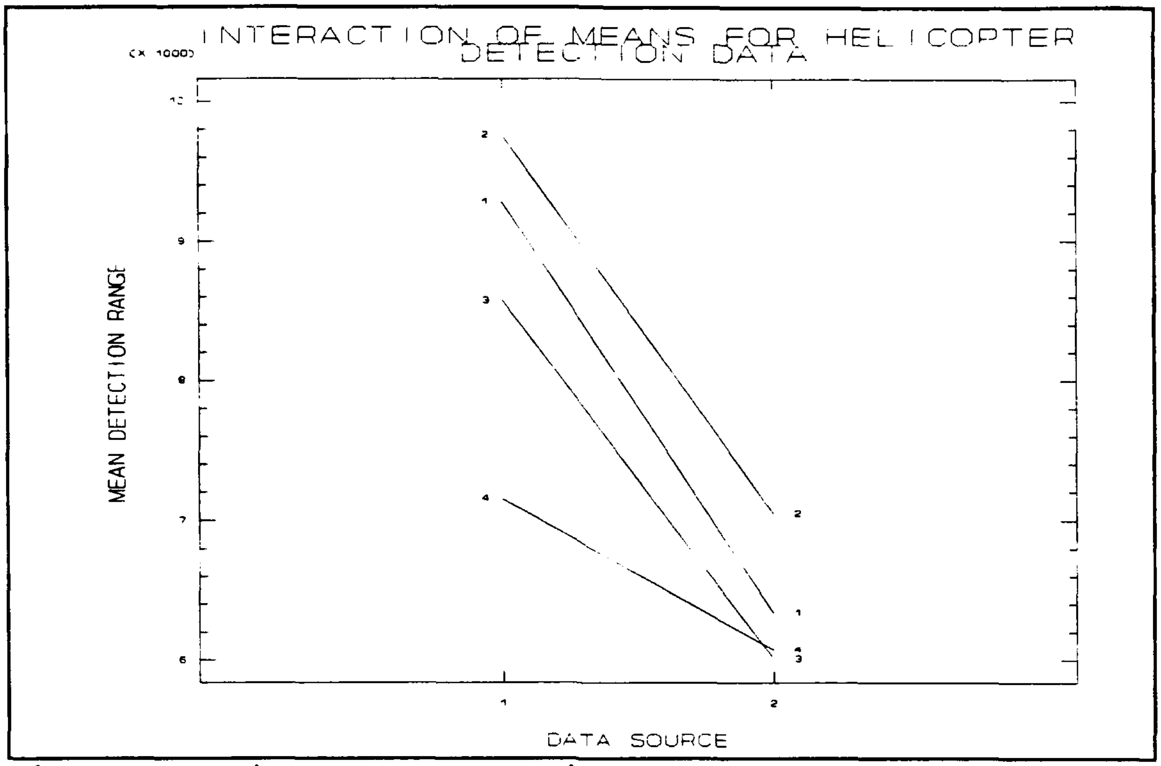

Figure 6 Helicopter Interaction of Means. Number Signify Trial.

The adequacy of the Two-Factor ANOVA was checked by testing whether the residuals have a normal distribution and whether the detection ranges have common variance. Figure 7 shows a graphical comparison of residuals to a normal curve. It suggests the residuals are not normally distributed. A Chi-Square Goodness of Fit Test verified this lack of normality, as the chi-square statistic is 87.93 (df=19) and has a significance level of .000. However, the robustness of the ANOVA test regarding lack of normality in the residuals makes it still valid but not as powerful [Ref 8].

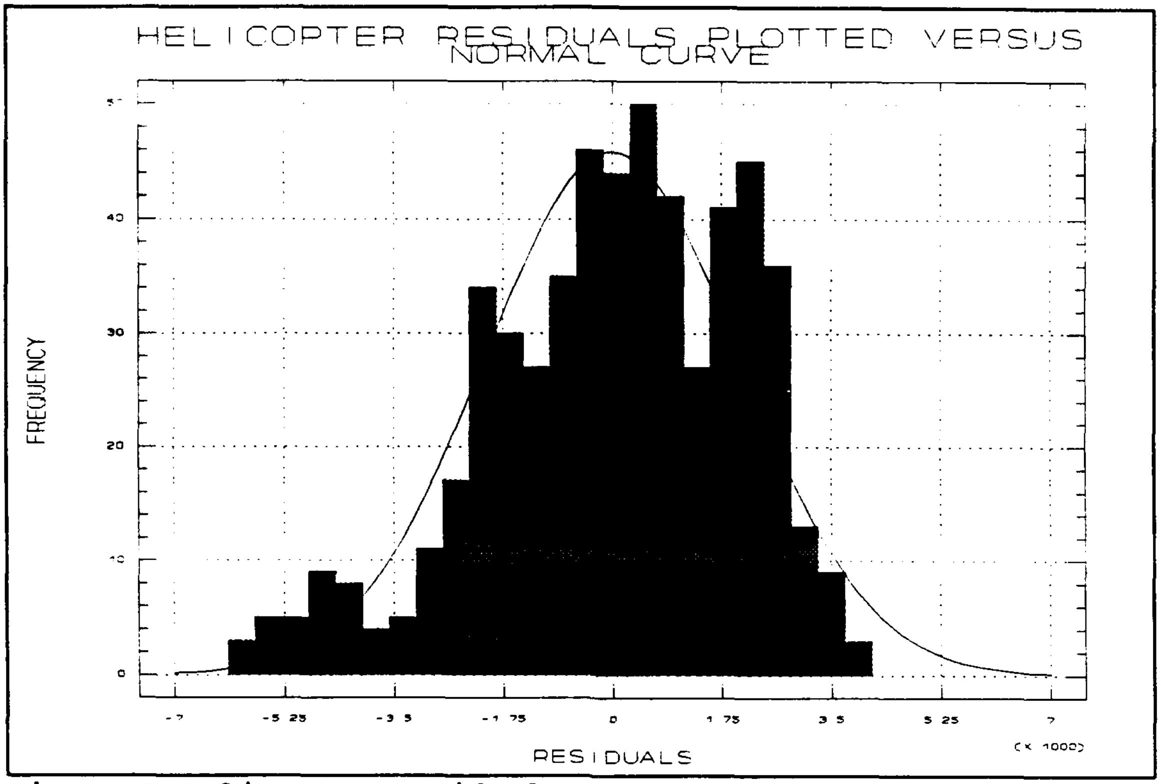

Figure 7 Helicopter Residuals Versus Normal Plot

The ratios of variances between each set of corresponding Janus and field test data indicate common variance per trial. Additionally, scatterplots of detection means versus standard deviations for each set of helicopter data, shown in Figure 8, indicate the similarity of standard deviations and the lack of any strong relationship between the mean and standard deviation. Therefore, the assumption of common variance appears valid.

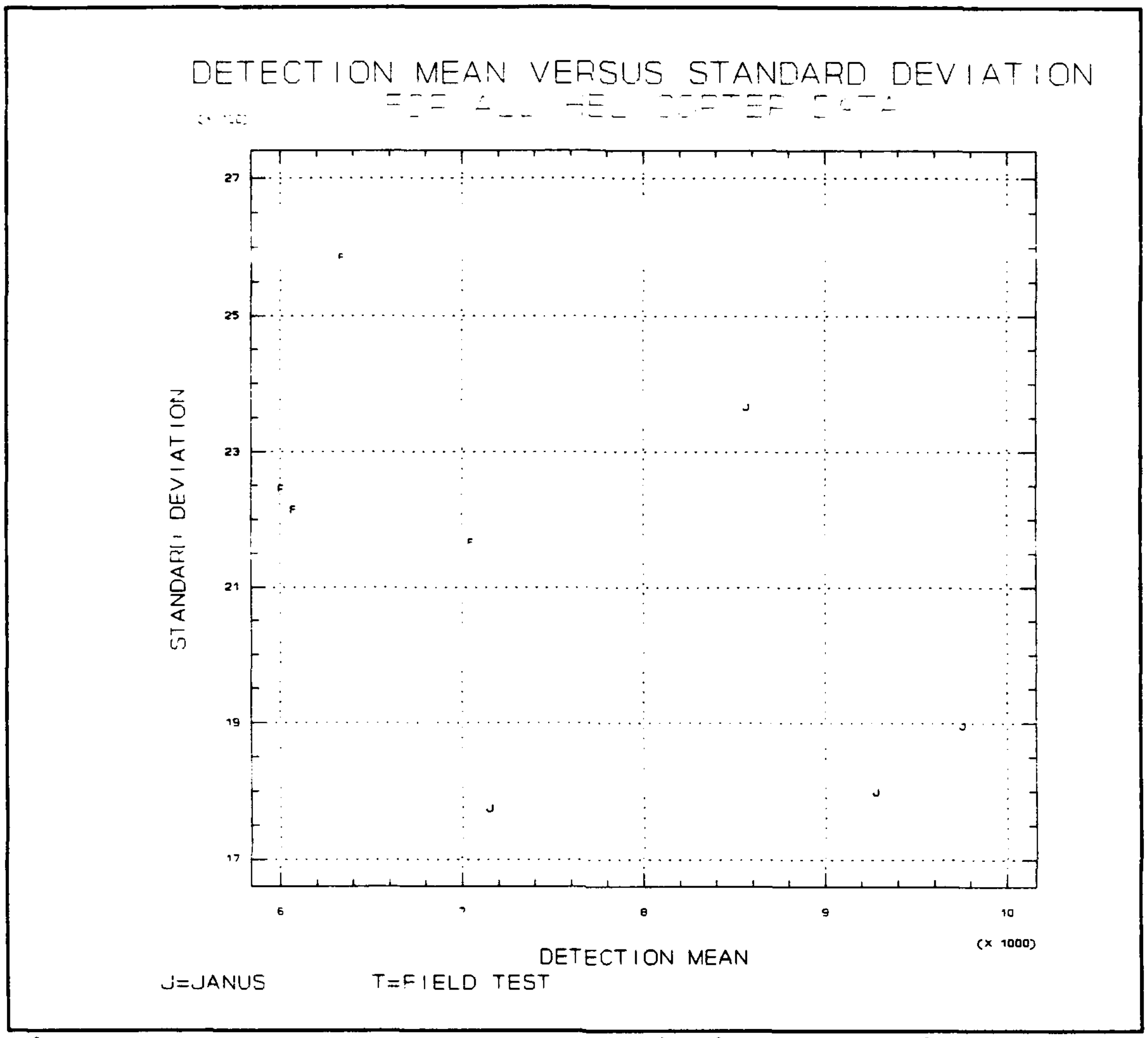

Figure 8 Means Versus Standard Deviation For Helicopters

An additional Two-Factor ANOVA was again run with the helicopter detection data using trials as one factor and data sources as the other factor. For this test, however, data source is split into the five levels corresponding to Janus iterations per trial; the sixth level of this factor is the field test. The resulting ANOVA summary is shown in Table VII.

Table VII ANOVA TABLE OF HELICOPTER DETECTION DATA

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARES	F-RATIO	SIG LEVEL
TRIALS	358,750,000	3	119,580,000	27.31	.000
DATA SOURCE*	452,840,000	5	90,567,000	20.68	.000
INTERACTION	69,738,112	15	4,649,207	1.06	.389
RESIDUALS	2,298,800,000	525	4,378,711		
TOTAL	3,242,600,000	548			

* 5 INDIVIDUAL JANUS ITERATIONS AND FIELD TEST EVALUATED SEPARATELY

Trials and data source factors are again highly significant. However, the interaction between trials and data sources is insignificant in this case, in contrast with the model used in connection with Table VI. This suggests that when the variability among Janus runs is accounted for, the apparent interactions become insignificant. The increase in interaction sum of squares in Table VII is more than offset by the increase in degrees of freedom.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The analyses of a limited set of data show that that Janus and field test aircraft detection ranges do not agree. Our conclusion is, therefore, that we are not able to validate or accredit Janus for use with Model-Test-Model at this time. This is due in part to the difficulty in replicating the field test process in Janus.

The comparison of fixed-wing data showed differences in the means of detection ranges between trials, but no significant difference between sources. Yet, the meaning of this result is not clear, since both sets of data being compared were limited. Additionally, the powers of the tests are low due to high variance and low field test sample sizes.

B. RECOMMENDATIONS

We have found that an attempt to replicate a field test trial in a simulation such as Janus requires a thorough knowledge of the field test by the modeler. Detailed information such as flight altitudes, speeds, movement routes used by aircraft and vehicles on the ground, and other characteristics not currently provided in field test data are needed. To ensure this is done, modelers and testers should closely coordinate prior to and throughout the field test.

Additionally, setting correct parameters within Janus is critical to the accurate portrayal of the weapon systems involved. The Army proponent is the most knowledgeable source of weapon capabilities, and should therefore work closely with the modellers prior to the pre-test to ensure the parameters are set correctly.

Another important finding is that detections are too difficult to measure in the LOS-F-H field test by the use of video data reduction. Other battlefield occurrences, such as engagements and kills, can be recorded in 'real time' in a field test environment. Future comparisons should use a phenomenon other than detections that is well defined and is recorded by the instrumentation.

Finally, the topic of MTM deserves further investigation. Future field tests of the M1A2 battle tank have already benefitted from the pre-test phase of MTM, and the data resulting from the upcoming M1A2 field tests should be analyzed and compared with Janus data, with the intent of validation or accreditation of Janus.

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